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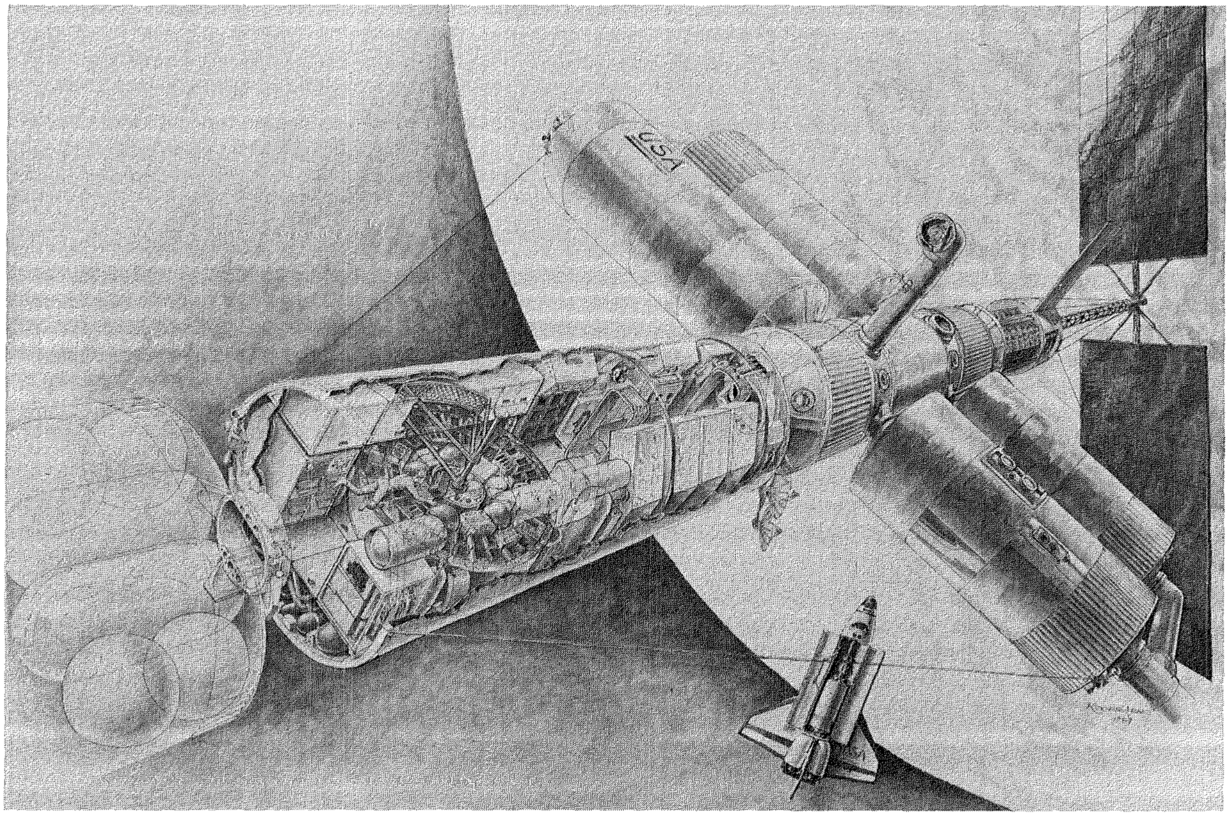
# Life Sciences Research on the Space Station — an Introduction

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# Life Sciences Research on the Space Station — an Introduction

Advanced Programs Office, Life Science Division
Ames Research Center, Moffett Field, California

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**Ames Research Center**
Moffett Field, California 94035

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## SUMMARY

The Space Station will provide an orbiting, low gravity, permanently manned facility for scientific research, starting in the 1990s. The facilities for life sciences research are being designed to allow scientific investigators to perform research in Space Medicine and Space Biology, to study the consequences of long-term exposure to space conditions, and to allow for the permanent presence of humans in space. This research, using humans, animals, and plants, will provide an understanding of the effects of the space environment on the basic processes of life. In addition, facilities are being planned for remote observations to study biologically important elements and compounds in space and on other planets (exobiology), and Earth observations to study global ecology. The life sciences community is encouraged to plan for participation in scientific research that will be made possible by the Space Station research facility.

## INTRODUCTION

In 1984, President Reagan, during his State of the Union Address, announced his decision to develop a permanently manned Space Station. His goal was to "do it within a decade" for the purpose of "peaceful economic and scientific gain and for quantum leaps in research and technology."

During the past decade, the Space Shuttle has been developed into a reliable transportation system capable of carrying people and equipment into Earth orbit and returning them safely. But the Space Shuttle can spend only a limited time in space. A Space Station will provide a permanent facility for scientific research and technology development while continuously orbiting the Earth.

An important segment of the initial Space Station configuration will be a science laboratory module (SLM). This laboratory module will include life sciences research facilities to conduct research: in Space Medicine, to study the effects of the space environment on humans to allow for our permanent presence in space; in Space Biology, to study the effects of space on the basic processes of life, in both animals and plants; and in other areas of biological research, using remote observations to study biologically important elements and compounds in space and on other planets, as well as the global effects of the biosphere on the planet Earth.

## THE SPACE ENVIRONMENT

### Microgravity

The force of gravity that we experience on Earth (1 g) plays a key role in much of biology. Plants grow upward partly in response to gravity. Animals' circulatory

systems distribute nutrients, and their skeletal systems provide support against the Earth's gravitational field. Many physiological and metabolic functions, and even the embryonic development of higher animals, may be heavily influenced by gravity. Physiological adjustments to the space environment, which have been observed during previous space missions, involve many tissues and organs, including the nervous, cardiovascular, muscular, and skeletal systems. On the Space Station, orbiting 250-300 miles above the Earth's surface, gravity will be near zero. This will provide an ideal environment to study the long-term effects of microgravity on human, animal, and plant systems.

### Other Environmental Factors

Because of the insulating effect of our atmosphere, environmental conditions may be present on the Space Station that are not experienced on the surface of Earth. One such condition is increased exposure to various forms of radiation and high-energy particles coming from the Sun or outer space. These radiations could be at especially high levels in times of solar flares, particularly for astronauts who may be outside the Space Station in a space suit. Other factors to consider are psychological and psychosocial stresses due to isolation, close quarters, continual group interactions, and intense work schedules.

## SPACE LIFE SCIENCES

NASA divides the field of Space Life Sciences into two broad areas: Space Medicine and Space Biology.

### Space Medicine

The study of the medical consequences of long-term exposure to space conditions is termed space medicine. These studies are necessary to assure the health, safety, well-being, and productivity of the flight crew, scientists, and even visitors making extended visits into space. Space medicine includes the following disciplines:

**Operational Space Medicine** includes the responsibility for assuring the health, well-being, and performance of personnel working in space.

**Biomedical Research** concentrates on investigating the medical problems encountered in space, with the objective of defining each problem, understanding the basic biological mechanisms involved, and finding a countermeasure for the prevention or cure of the problem.

**Human Factors** includes research on human behavior and performance, the integration of human and machine, visual perception, group interaction factors, and recreational or creative activities affecting the quality of life.

## Space Biology

Space biology incorporates the study of how gravity has shaped and affected life on Earth and how living systems adapt to the virtual absence of gravity, and research which utilizes the unique environment of space to further our understanding of basic biological phenomena. In addition, space biology includes studies of the evolution and distribution of life in the Universe, and the use of space as a remote observation point to study the ecology of the Earth. Space biology includes the following research areas:

**Space and Gravitational Biology** involves the basic responses of living systems to the conditions present in the space environment. It includes animal and plant physiology, reproduction, growth, development, and aging. Of particular interest is an increased understanding of how gravity has influenced the evolution of life on Earth.

**Planetary Biology**, or exobiology, involves the study of the origin, evolution, and distribution of life in the Universe. This includes searching for biogenic materials and determining the fate of life in the Universe. The effect of biological processes on planetary evolution, and how terrestrial evolution has been influenced by space events is also of interest. For example, one recent theory proposes that the impact of a large meteorite with the Earth caused the extinction of the dinosaurs.

**Global Habitability**, or "biospherics," involves the use of optical and other electromagnetic (e.g., radar) sensors located in space, to study Earth's biological ecosystems on a global basis. The Space Station will act as an ideal platform for this remote sensing of the Earth's environment.

# THE SPACE STATION

## Space Station Design

After considering various designs for the Space Station, NASA has designated the "Power Tower" as the reference configuration (figs. 1 and 4). This is a long truss structure, up to 450 ft, that will travel in orbit with its main axis perpendicular to the Earth's surface. The top, or deep-space end of the structure, will hold the solar power panels, communications, cooling, and other support equipment. The bottom, or Earth end of the structure, will hold pressurized modules which will serve as living quarters for the crew and as research laboratories. Astronomical research instruments will be mounted at the top while Earth observation instruments will be located in the laboratory modules or outside on the bottom of the truss structure.

## Modular Construction

Because of its large size, the Space Station must be prefabricated in sections, or modules, which can fit into the Space Shuttle's cargo bay and then assembled in orbit. The Shuttle's cargo bay is approximately 60 ft long and 15 ft in diameter. The lifting capacity of the Shuttle is about 65,000 lb, but because of safety requirements, the Shuttle cargo load may be limited to approximately 35,000 lb. The

Space Station structure will weigh at least 200,000 lb on Earth, and will carry as much as 200,000 lb of equipment, research instruments, and supplies when in orbit. Simple arithmetic indicates that the initial Space Station will require at least 12 Shuttle trips to transport all of the components into orbit. Resupply and crew rotation is scheduled for 90-day intervals. However, other Shuttle visits may be necessary from time to time to deliver new facilities and equipment and to return used ones.

### Common Modules

For cost effectiveness, and to conform to the cargo requirements of the Space Shuttle, the living and laboratory facilities will be made up of cylindrical pressurized modules 14.5 ft in diameter and 35-45 ft long. Initially, it is anticipated that the Station will have five modules. Two "habitability" modules will provide living quarters for six to eight crew members. Two research laboratory modules, one for sciences, including life sciences, and one for commercial and materials experiments, will be used. These laboratory modules will contain equipment and instruments to accommodate user requirements. The fifth module will be a detachable logistics module which will serve as a storage area for supplies, and will be exchanged every 90 days by the resupply Shuttle. Figure 1 illustrates one possible configuration for the initial five modules. Additional modules will be added as the Space Station grows and evolves to meet our future needs for research in space. Alternate arrangements of the modules on the truss are possible. A diagram of the inside of a common module is shown in figure 2.

## LIFE SCIENCES RESEARCH FACILITIES

### Size and Configuration

The external size and shape of the science laboratory module (SLM) will be set by the common module design. The outside dimensions will be 14.5 ft in diameter and 35-45 ft long. The usable research laboratory space will be restricted by hatches and passageways, and by the common life support, environmental control, and safety equipment. In addition, space within the SLM will be shared by researchers from various scientific disciplines. Figure 3 shows the possible vertical and horizontal layout designs for the science laboratory module.

### Facilities and Equipment

The laboratory outfitting for life sciences will be determined by user needs, technological limits, and cost constraints. Categories of equipment being considered for inclusion are general research support equipment, specific analytical research instruments, and data-processing and communications equipment, including video monitoring. Special-purpose facilities such as animal habitats, plant-growth chambers, pilot waste recycling and food production units, and variable-gravity, specimen-research centrifuges are also under consideration. The facilities and equipment will be modified or changed as experiments are completed and new research is started. The appendix lists some of the anticipated equipment needs for human, animal, plant, and other biological research.

## Experiment Management and Resupply

As indicated previously, present mission plans call for resupply to be at 90-day intervals. This means that careful planning must be performed to ensure that all specimens, materials, equipment, and supplies are delivered in a timely manner to and from the SLM for each operating experiment. Research equipment and procedures are often modified as conditions and data are evaluated during the course of an experiment, but these modifications must be anticipated as much as possible, since new equipment or materials will be limited to the established resupply schedule. Careful research experiment planning will also be critical because of the space and weight limitations of the SLM and the Shuttle. Crew time availability will also be limited, since there will be only six or eight people to operate the entire Space Station. Of these, perhaps only one or two will be mission specialists trained in life science research procedures, or principal investigators traveling with their experiments. Therefore, because crew time will be so precious, as many routine laboratory tasks as possible should be automated.

# LIFE SCIENCES RESEARCH OPPORTUNITIES ON THE SPACE STATION

## Space Medicine and Gravitational Biology

NASA experiences with previous space flight missions, and data shared by the U.S.S.R. from their biosatellite missions, indicate that microgravity causes numerous physical and physiological changes in humans and other organisms. For example, gravity has been shown to play a significant role in the growth and development of animals and plants. Therefore, research on the causes and mechanisms of changes in living systems in the microgravity environment is basic to the understanding of life on Earth. In addition, the development of countermeasures to the adverse effects of extended microgravity on space personnel is critical to allow for extended manned space missions.

Although the research opportunities associated with the reactions and adaptations of terrestrial organisms to microgravity are almost unlimited, the following are the areas of most immediate interest:

<u>Bone Physiology</u>- Study of the processes underlying bone demineralization and other alterations in microgravity, and methods of prevention.

<u>Cardiovascular Physiology</u>- Study of the causes and effects of the headward shift of body fluids, and of the changes in blood volume and electrolytes immediately upon exposure to weightlessness. Study of the reduction in heart mass, and altered heart action, and the associated problems of reentry and adaptation to the Earth's gravity. Studies of potential countermeasures.

<u>Muscle Physiology</u>- Study of the mechanisms underlying the atrophy of skeletal antigravity muscles, especially in the legs, and the development of countermeasures to prevent muscle atrophy.

<u>Neuroscience</u>- Study of the cause and mechanisms of space motion sickness, including the vestibular apparatus and associated structures, and the development of countermeasures.

Metabolism- Study of the control and regulation of metabolic processes, including mineral, energy, protein, carbohydrate, and fat metabolism.

Endocrinology- Study of the nature of the changes in the hormonal systems regulating the body's functions as one adapts to microgravity and readapts to the Earth's gravity.

Plant Growth and Physiology- Study of plant gravitropism, the mechanisms by which plants respond to gravity, and the effect of microgravity on growth, development, reproduction, and circadian rhythms.

Research and development of a Controlled Ecological Life Support System (CELSS) to recycle waste products and to produce food, air, and water for human consumption in orbit.

Embryology, Reproduction and Development- Study of the reproduction, development, and aging of organisms in microgravity. The evaluation of how animals that are born and raised in microgravity adapt to the Earth's gravity. This work involves multiple-generation studies.

Radiation Biology- Study of the cumulative radiation effects of ionizing and nonionizing radiation. Evaluating how DNA damage and repair are influenced by radiation in microgravity.

Human Behavior and Performance- Study the potential effects of stress that may develop from conditions of physical and social isolation, boredom, lack of sleep, threat of potential hazards, and discomfort associated with confinement, lack of privacy, and microgravity.

## Planetary Biology

Research opportunities on the Space Station in planetary biology (also referred to as exobiology, the study of biological processes occurring beyond the Earth) provide a unique vantage point from which to examine the evolution of life in our solar system and to determine the existence of extraterrestrial life. These studies primarily focus on the biogenic (literally life-forming, or life-producing) elements which result from, or are essential to, the processes of life.

A rich array of organic compounds have been found in the most numerous class of meteorites: the stony (generally nonmetallic) carbonaceous chondrites. To locate other, possible prebiological, forms of carbon, a Space Station would provide a useful platform from which investigators can collect dust particles, which could be studied and traced back to their origin from Earth, Sun, comets, meteorites, or interstellar space. Comets are believed to contain the best examples of biogenic elements and compounds from the earliest days of the solar system, because in orbiting the Sun eccentrically comets would preserve these specimens in deep-freeze.

Interstellar particles could also serve as model grains for life scientists on the Space Station to study the chemical processes leading to their formation in the vacuum, radiation, and microgravity conditions of space. Grains could be artificially synthesized to study, in miniature, the formation of biogenic elements believed to occur on the surface of meteorites and comets, and in solar nebulae and interstellar space.

Spectrophotometry from Earth-orbiting telescopes can also be used to observe absorption and emission lines of the biogenic elements and compounds in comets, planetary atmospheres, and nebullae. The abundance of these elements, for example, in dense interstellar clouds, could also indicate the prime conditions and locations for the evolution of life in the universe. Figure 4 illustrates the Space Station with the attached telescopes and electronic equipment located on the upper boom, and also shows a co-orbiting platform which could also hold Planetary Biology research equipment.

## Global Habitability

During the twentieth century, of the 15 million animal species on Earth, humans alone utilize approximately 40% of the total production of the planet. Consequently, it is of critical importance that we manage the Earth's scarce resources so as to ensure and sustain the quality of air, water, and chemical and biological materials that are essential for life. The first step in that process is to expand upon the existing body of knowledge and refine and develop research methods that enhance our information concerning the terrestrial environment and its resource base.

Space Station research opportunities in global habitability address these issues via biospheric remote sensing on a global scale. This provides the ability to assess the impact of natural and human-caused changes in the processes that regulate the flow of chemical compounds through various biomes; for example, a temperate forest, a coral reef, an urban valley, or a boreal (northern) ecosystem.

High-resolution photographic and digital image products from space require extensive data processing to yield information regarding issues of global habitability. Since different land cover surfaces reflect varying amounts of visible and infrared light in the different regions of the electromagnetic spectrum, the life scientist can utilize remotely sensed data to develop a "signature" for each surface material (trees, grasses, water, etc.), as shown in figure 5.

High-spectral-resolution data (in combination with high sampling frequency) in the next generation of sensor systems will facilitate the study of variations in life-dependent compounds within and between ecosystems. Plant density, temperature, and other measures also facilitate the study of large-scale stress responses in the environment caused by ozone, acid mist and fog, urban pollution, forest fire, and trace-element toxicity from agricultural waste water (which is common to irrigation of arid land). Ecosystem signatures may also permit estimates of large animal populations, and perhaps even the range and spread of selected insect species.

The low spatial and spectral resolution of sensors on the first generation of Landsat satellites proved inadequate to obtain all the necessary data for life science research. The development of the next generation of sensing systems, combined with reduced launch cost and increased launch frequency of the Shuttle, and the relative ease of long-term testing from a human-tended Space Station, will speed the evolution of biospheric ecosystem science. In support of this effort, work has already begun among many NASA centers to develop and integrate pilot data systems on various biomes to support laboratory, field, and space research with a global resources information system.

## SPACE STATION PROGRAM SCHEDULE

The program schedule for the development of the Space Station is shown in figure 6. It can be seen that this large and complex project is divided into several phases, resulting in an operational Space Station as early as 1992, the 500th anniversary of Columbus' discovery of the new world.

It can be seen in the proposed program schedule that the selection of the initial life sciences research experiments for the Space Station may not be made until 1987 or 1988. This means that there is still time for scientists who are interested in conducting life sciences research experiments on the Space Station to make their plans to respond to the NASA requests for Proposals when they are issued.

Those interested in additional information on life sciences on the Space Station should contact NASA at one of the following addresses:

Life Science Division
Chief, Advanced Programs Office
NASA Ames Research Center
Moffett Field, CA 94035

or

Life Science Division
NASA Headquarters
Washington, D.C. 20546

# APPENDIX

## RESEARCH LABORATORY EQUIPMENT

### Basic Research Support Equipment

Accelerometer Measurement System
Dynamic Environment Measuring System
General-purpose Workbench
Refrigerator
Freezers, -70° and Cryogenic
Incubator
Sterilizer
Microscopes, Binocular and Dissecting
Laboratory Centrifuge
Specimen Mass Measurement Devices
Biomedical Recorder
Oscilloscope
Radiation Dosimeter
Fluid Handling Kit
Hematology Kit
Veterinary Kit
Surgery/Dissection Kit
Plant Tool Kit
Microprocessor
Video Camera and Video Cassette Recorder
TV Monitor and Voice Recorder

### Vivaria

Automated Small Animal Holding Facilities/Rodent Habitats
Rodent Breeding Habitats
Small Primate Habitats
Restrained Large Primate Holding Facility
Unrestrained Large Primate Holding Facility
Avian Habitats
Aquatic Animal Holding Facility
Plant Growth Facility

### Specimen Research Centrifuge

1-g Centrifuge for Experimental Controls
Variable-Gravity Specimen Research
Specimen Research Habitats on the Centrifuge

### Analytical Research Instruments

Metabolic Measurement Facility
Animal Physiological Monitoring Systems/Biotelemetry
Mass Spectrometer
Gas Chromatograph
Scintillation Sample Analyzer
Spectrophotometer

Lower-Body Negative-Pressure Device
Pulmonary Function Analyzer
Echocardiograph
Plethysmograph
Other User-Defined Instruments

Remote-Sensing Equipment

Image-Processing Facility Hardware, Software, and Associated Peripherals
Spectrophotometer
Field Sampling Equipment
Data Logger
Field Reflectance Spectrometer
Stereoscopes
Radiometer

Planetary Biology Equipment

Cosmic Dust Collector and Detector
Gas Grain Simulation Facility

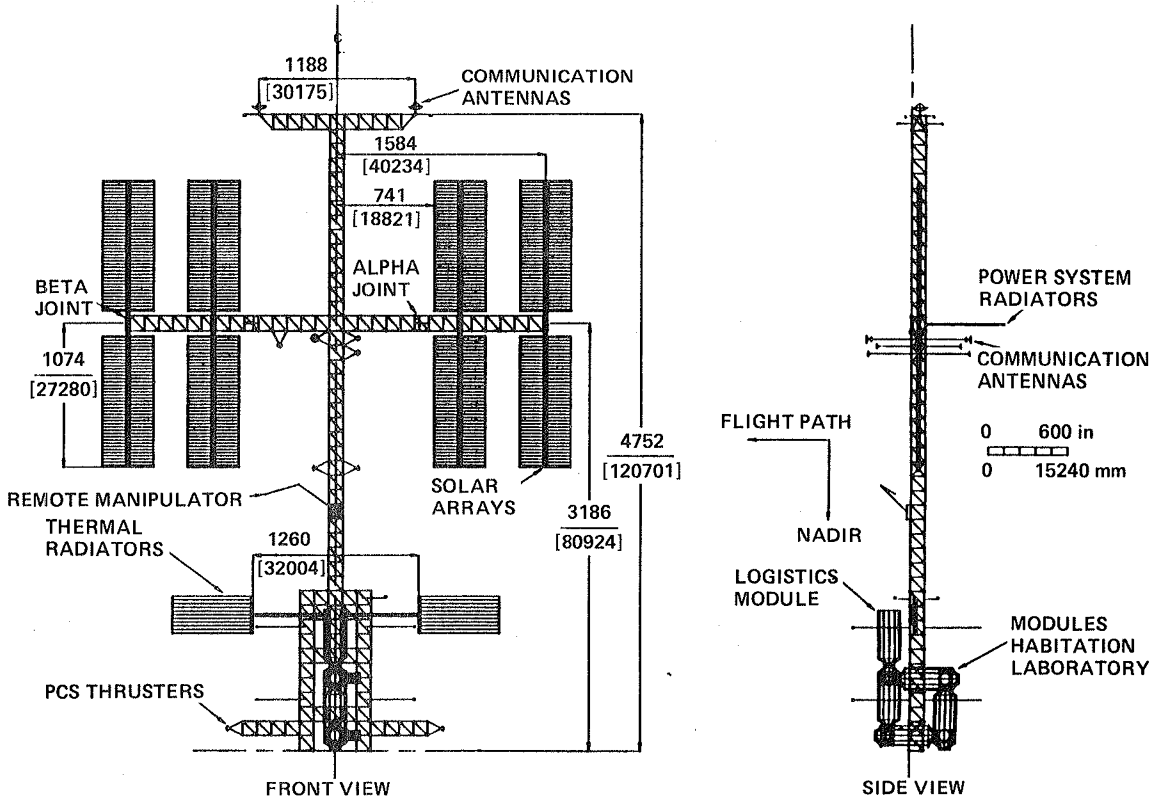


Figure 1.- Manned core space station reference configuration.

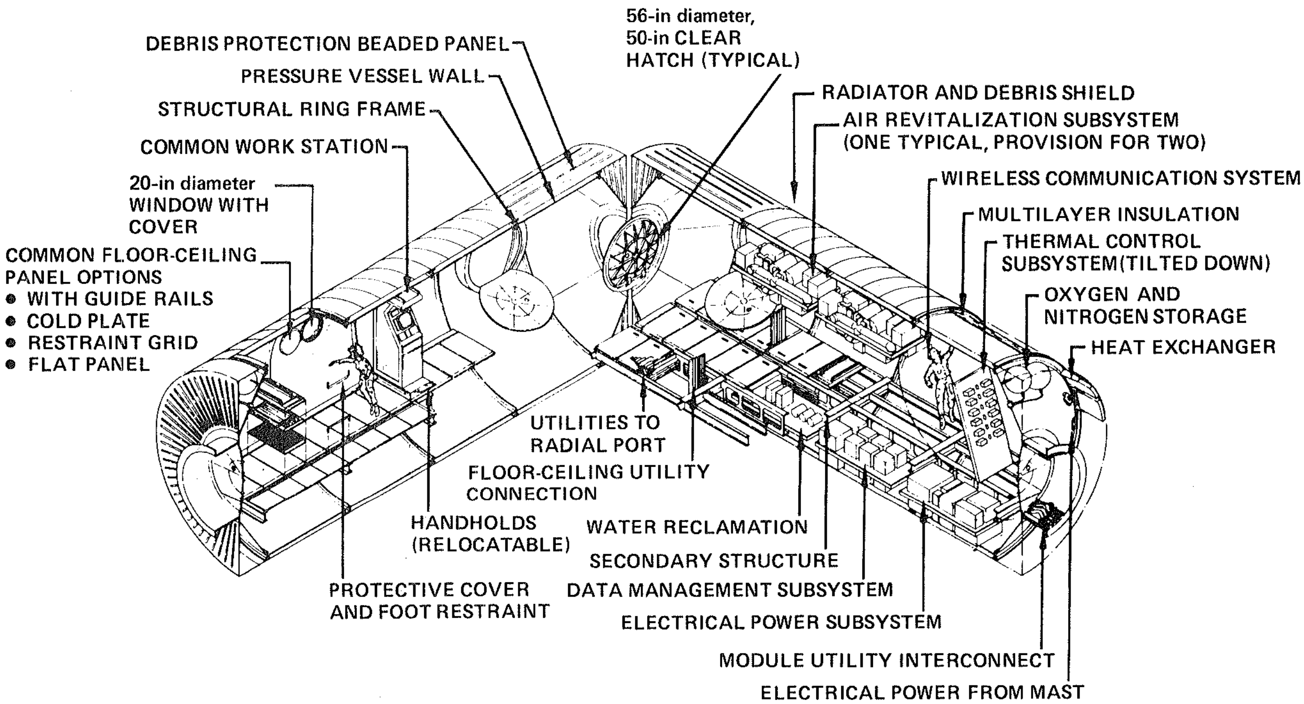


Figure 2.- Typical common module.

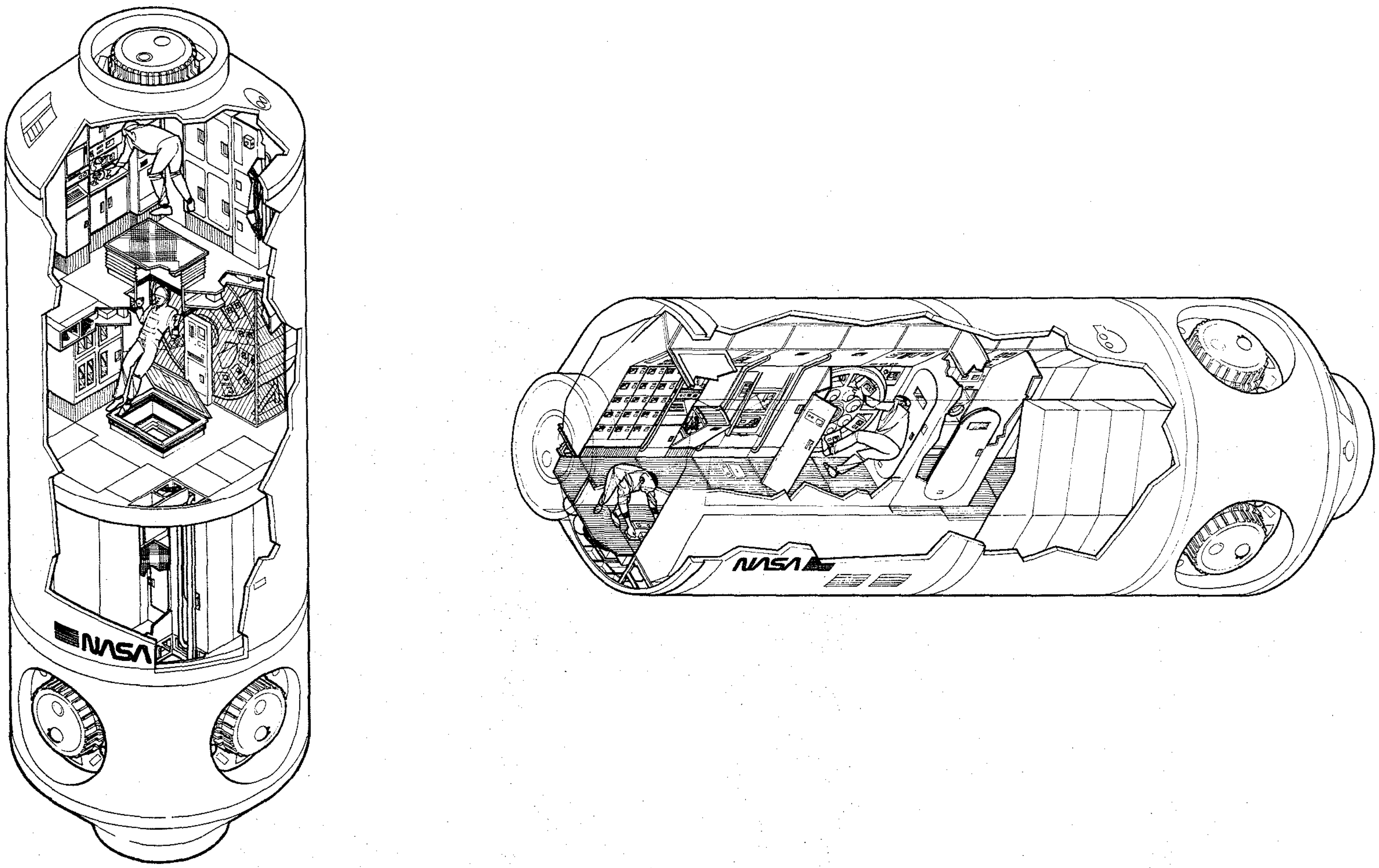

Figure 3.- Possible vertical and horizontal layouts for the science laboratory module.

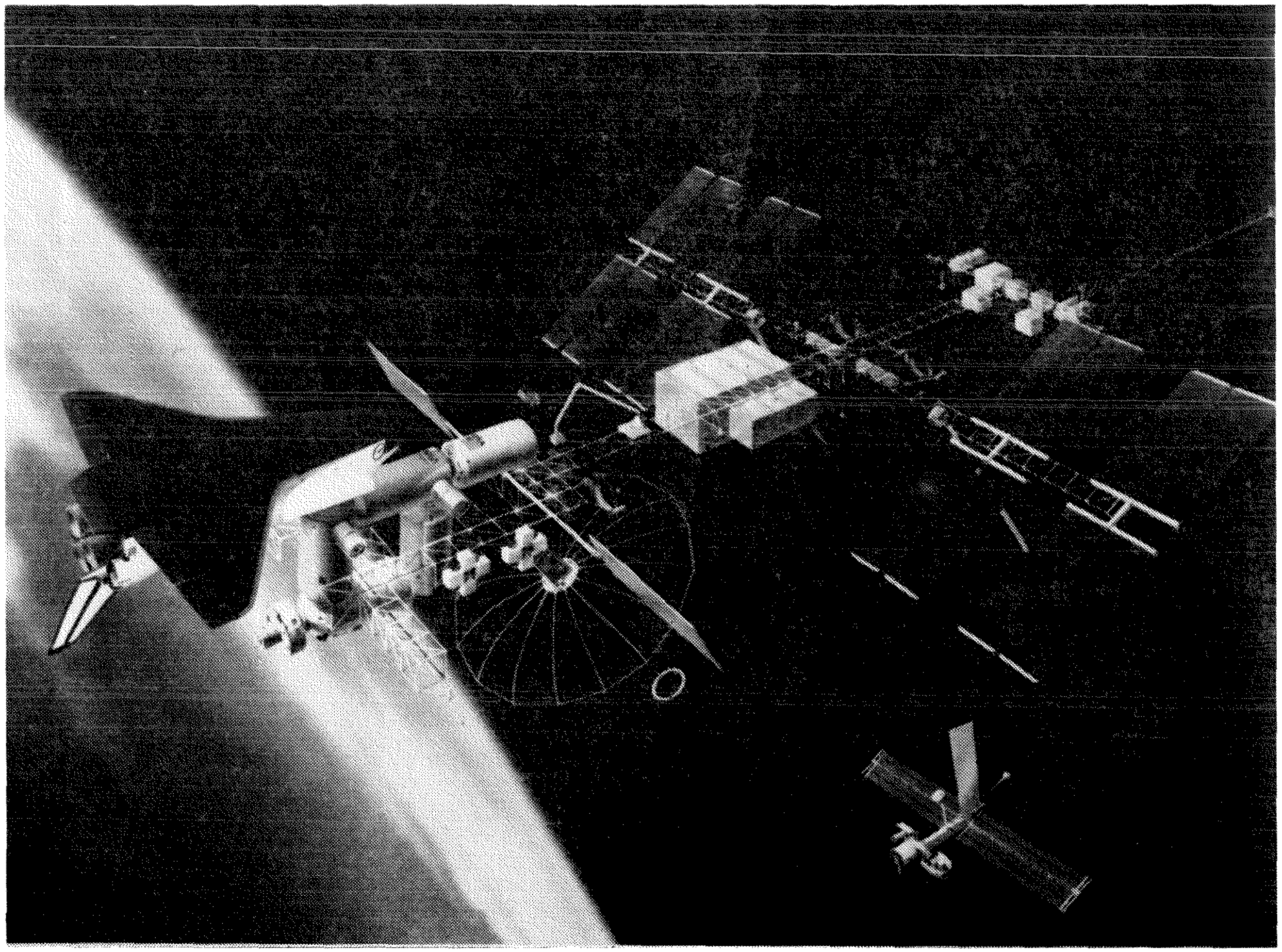

Figure 4.- Space station with attached telescopes and electronic equipment, and co-orbiting platform.

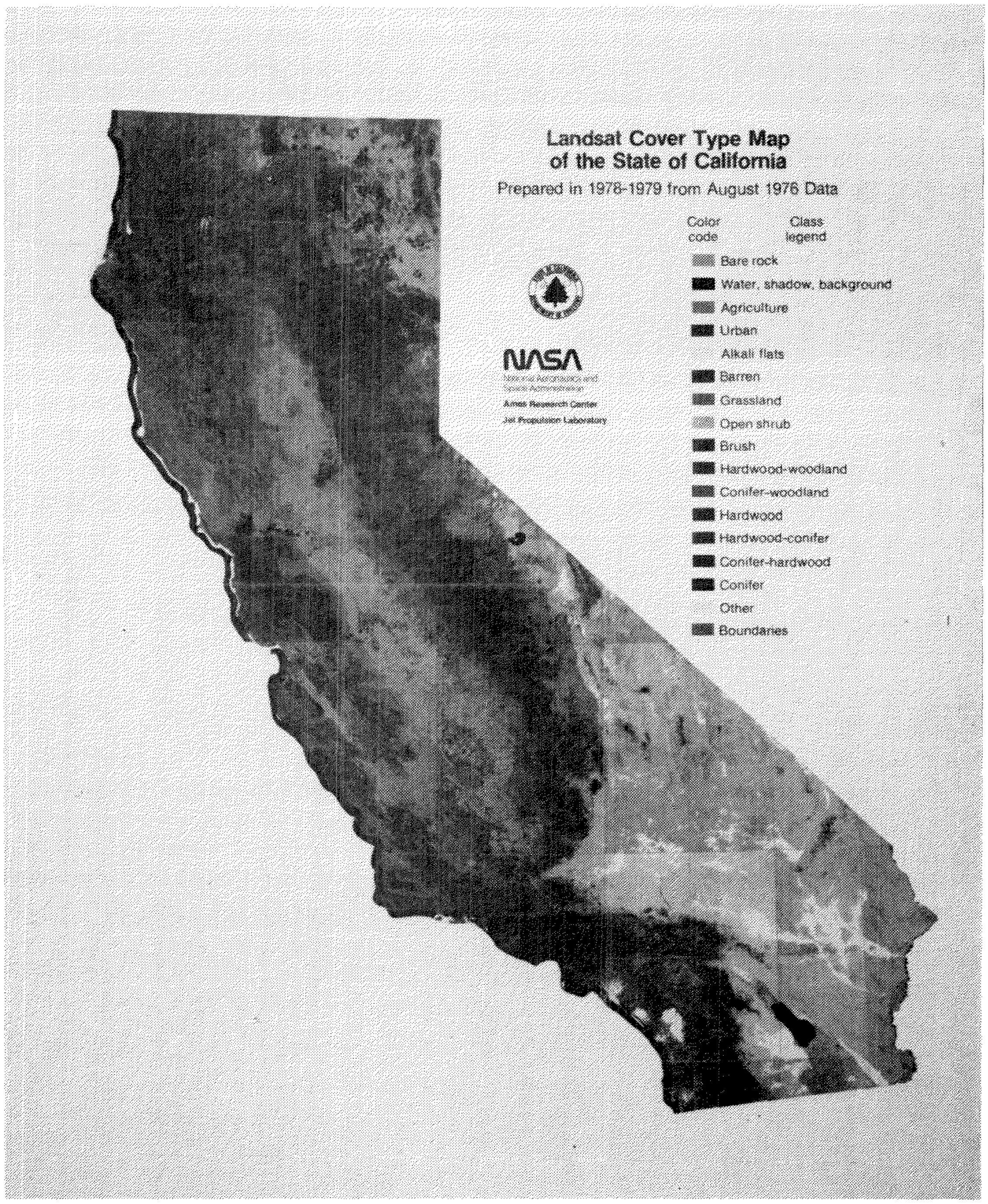


Figure 5.- Principal types of land cover in California were determined using Landsat satellite data. The urban areas, in purple, are clearly distinguishable from the adjacent forested areas, in shades of red, and farmland, in yellow. The next generation of sensing systems on Space Station will provide even higher detail to study the cycling of important biological compounds, and the effects of pollution and natural changes in the environment.

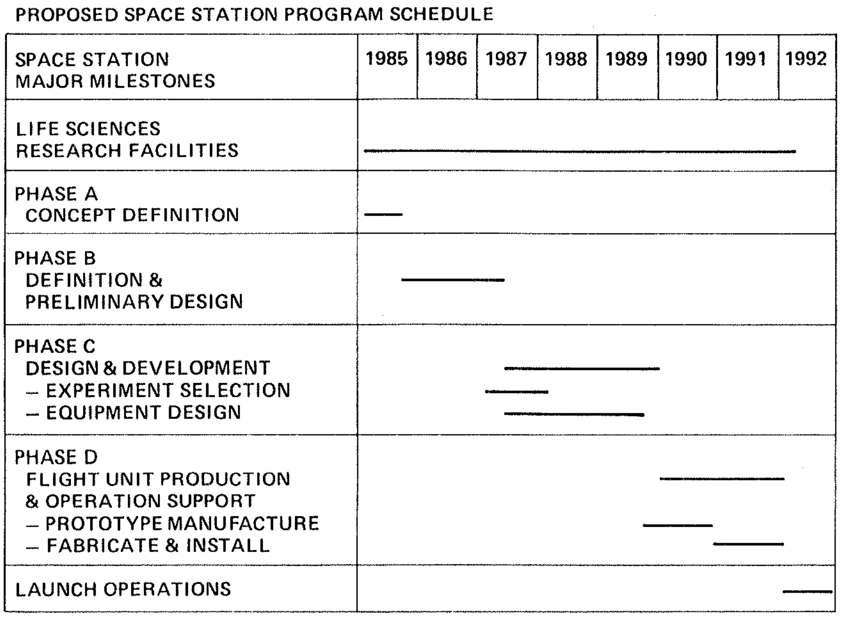


Figure 6.- Program schedule for development of the Space Station.

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15. Supplementary Notes

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16. Abstract

The Space Station will provide an orbiting, low gravity, permanently manned facility for scientific research, starting in the 1990s. The facilities for life sciences research are being designed to allow scientific investigators to perform research in Space Medicine and Space Biology, to study the consequences of long-term exposure to space conditions, and to allow for the permanent presence of humans in space. This research, using humans, animals, and plants, will provide an understanding of the effects of the space environment on the basic processes of life. In addition, facilities are being planned for remote observations to study biologically important elements and compounds in space and on other planets (exobiology), and Earth observations to study global ecology. The life sciences community is encouraged to plan for participation in scientific research that will be made possible by the Space Station research facility.

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